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STAR POSITIONS AND GALACTIC CO-ORDINATES.[1]

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"The galactic circle, the great circle to which the course of the *Via Lactea* most nearly conforms. Every subject has its technical or conventional terms, by whose use circumlocution is avoided and ideas rendered definite. This circle is to sidereal what the invariable ecliptic is to planetary astronomy—a plane of ultimate reference, the ground-plane of the sidereal system."—Sir J. HERSCHEL, *Outlines of Astronomy*, 1849, page 53.

In nearly every case concerning the motions of the heavenly bodies, the astronomer has to refer their places to the center of the Sun; so that if an observer could be heliocentric much labor of reduction would be saved. Let us try to imagine how a heliocentric observer, with all our notions upon astronomy, would start to work. His first object would be to form a catalogue of the stars, and to do so he would have to decide on the planes of reference to which their places should be referred. If a terrestrial friend should suggest that the plane of the Earth's equator should be the fundamental plane and that the direction of the intersection of the Earth's orbit with its equator should be the initial plane, I think our heliocentric astronomer would be surprised. He might say: "But both the Earth's orbit and its equator are changing constantly, and the stars are virtually fixed; would I not by choosing such co-ordinates involve myself in endless calculations? Why should I not choose some plane and starting-point nearly invariable and related in some way to the stars?" The terrestrial astronomer could only reply that his predecessors had used the Earth's equator, etc., and that the theory of meridian instru-

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ments which they used was based on the fact that the Earth rotates. But what, the heliocentric astronomer might ask, has the Earth's rotation to do with the places of the stars? Would not the stars still be in their places if the Earth ceased to rotate? Why not fix the places of your stars by photography? It gives results more precise than any meridian instrument, and from these precise places, you may, if you wish, find out the positions of the Earth's equator and orbit, but do not mix your ideas and put the cart before the horse.

How is it that sidereal astronomy has got so involved? I think the difficulty grew in this way. Precise astronomy commenced about 1750. It is interesting to note that the oldest catalogue that the astronomer keeps on his working shelf is for the epoch 1750 and was compiled from LACAILLE's observations made in Strand Street, Capetown, with a ½-inch telescope. The other star catalogues between 1750 and 1800 are due to the labors of BRADLEY, MAYER and LALANDE. But the work of these four astronomers is remarkable in this, that although they made the observations, they did not reduce them. The prison-house of variable right ascensions and declinations was not yet ready. But early in the nineteenth century, BESSEL got all into ship-shape order. BESSEL's aptitude for all the problems of spherical astronomy was marvelous; so that to a subject which seemed unwieldly in its clumsiness, he managed to fit formulas of, when the complexity of the subject is considered remarkable neatness. The relief was so great that astronomers accepted the fetters gleefully. BESSEL's star-reduction numbers, which are published in every astronormal ephemeris, provide for the aberration of light, nutation in latitude and longitude, and the precession of the equinoxes. Thus encouraged, astronomers soon reduced the observations of LACAILLE, BRADLEY, MAYER and LALANDE to mean epochs. So long as the stars concerned are not very near the poles of the rotating sky, and the period does not exceed one century, the precession formulæ are not too unwieldy. One has to calculate for both right ascension and declination the first term of the precession which will be multiplied by t, the time elapsed, then the secular variation which is to be multiplied by $t^2/200$, then the third term of the precession, which will be multiplied by t^3. It is true that for many thou-

sand of stars these precessional terms are already calculated, and all that remains is for the user of a catalogue to do the multiplication by t, $t^2/200$, and t^3. But the labor of making all these calculations is prodigious and it is all done to impress an imaginary motion upon the fixed stars. This motion makes it difficult to compare the places of stars in different catalogues. Thus we have in catalogues the following positions of ϵ *Orionis*:—

Catalogue.	Epoch.	R. A.	Dec.
LALANDE	1800	$5^h\ 26^m\ 3^s.66$	$-1°\ 20'\ 27''.2$
British Association	1850	$5\ 28\ 36.22$	$-1\ 18\ 6.5$
Cape	1900	$5\ 31\ 8.36$	$-1\ 15\ 56.5$,

indicating change in one century of

R. A. $+5^m\ 4^s.70$ Dec. $+4'\ 30''.7$,

whereas the real movement of the star in that time has only been $11''.66$ in all; the rest is fictitious.

The use of the moving or equatorial co-ordinates of right ascension and declination is inevitable for some purposes, such as in determining the places of the Sun, the interior planets, *Mercury* and *Venus,* and the clock-stars; for finding with an equatorial telescope, rough equatorial co-ordinates such as can be read off a good star map by inspection are all that are required. Why should we, therefore, impose moving co-ordinates on millions of fixed stars because we require moving co-ordinates for the Sun and a few planets and clock-stars?

I think that the reason astronomers have kept to moving co-ordinates was a belief that the use of galactic co-ordinates, to coin a term suggested not only by the nature of the problem, but by Sir JOHN HERSCHEL, would lead to formulas of even greater complexity than those given by BESSEL. When I proposed the use of galactic co-ordinates, a well-known astronomer wrote me that the idea was attractive, but that no one would look further unless numerical examples showing how it worked in practice were forthcoming. I must confess that when I took up this challenge I was not too confident that the formulas would work. In the result, I was agreeably surprised; the resulting expressions, even in the most disadvantageous cases, are hardly longer than the old methods, and in all others they are shorter and sometimes very much shorter.

If this was the only gain, it would be considerable, but the real gain is behind this; the positions furnished by the galactic co-ordinates are final; comparisons betwixt star catalogues will become immediate. To work out a proper-motion of a star to-day requires hours if not days of work, because of the fictitious movements impressed upon it. With galactic co-ordinates, the comparison will be the work of minutes, and will moreover yield the proper-motion referred to its natural plane.

One cannot but regret that in planning the great *Carte-du-Ciel* the advantages of a proper system of co-ordinates were ignored. Let us look at the difficulty which the system adopted leads to. To take, as an example, the Cape *Carte-du-Ciel* Catalogue, we learn from Mr. HOUGH'S last report that it will fill eleven quarto volumes and give the positions of about 990,000 stars in all. At the same rate the complete sky *Carte-du-Ciel* catalogues will furnish the places of some 13,500,000 stars. These are all to be referred to the mean equator and mean equinox of 1900. If the catalogue is repeated, as is the implied intention, in another century (or less as I hope), and it is referred to its mean epoch, any comparison between the two catalogues will be extremely laborious because the effect of precession on the so-called standard co-ordinates is complex. But let us assume that instead of 13,500,000 stars there are only 8,000,000 catalogued and that each star can be effectively compared in ten minutes of time, then the complete comparison will occupy one man's full time for 555 years, and, at the moderate salary of £200, cost £110,000. I fear that there is a danger here in that the *Carte-du-Ciel* scheme is strangling itself so far as useful work goes by adding so enormously to its load of inertia. Had the places been referred to the galactic system by the use of galactic plate centers and secular co-ordinates, comparisons would be practically instantaneous.

There is, however, a saving clause. When the *Carte-du-Ciel* scheme was started in the 1880-1890's, astronomers tacitly assumed (forgetting PROCTOR'S work) that each star moved on its own — was an individuality distinct from its neighboring stars; an assumption engendered by the known motions of the brighter stars then most studied. To-day it is known that stars are traveling in communities and that the number

of these communities is not large; that they, perhaps, can be counted on the fingers of one hand; but it would not matter if there were one thousand communities—it is much easier to deal with one thousand communities than with 13,500,000 individuals; and it is also known that the number of large or eratic proper-motion stars is very restrained. Hence, the real value of the *Carte-du-Ciel* consists in its photographs or their enlargements; in fact, in the *Carte-du-Ciel* and not in the places of stars derived from it. Examination of these *Cartes* taken at different dates by means of superposition and projection in an enlarging lantern or by a blink-apparatus (as made by Messrs. ZEISS) will at a glance discriminate those stars which are moving "out of community." Measures of these and of *a few* of those moving "in community" will give all the information as to these motions which is required. By this means instead of measuring on an average three hundred stars per square degree, about eight or nine will suffice. The saving from this point of view alone is forty-fold.

A superficial criticism is that the galactic plane is not rigidly marked on the sky. But is the equator? The former is defined by the galactic latitudes of the stars at the chosen epoch and at later epochs by such latitudes as will reduce the totality of proper-motions (freed from the effect of motions of the solar system) to a minimum. To this plane must be referred the equator and equinox of the Earth, and not *vice versa*. In the future, star-places will be determined solely by photography, but to-day we are in a transition period and one of rivalry. But where the ultimate victory will be is not uncertain. If we look over Boss's Preliminary Star-Catalogue, we see that with hundreds of observations spread over a century, we may hope to know such a well-observed star's place, as determined with meridian instruments, with an accuracy of about $\pm 0''.05$ at the center of gravity of the observations, or of $\pm 0''.1$ forty years afterwards. Professor KAPTEYN, in measuring photographs of the *Hyades* group of stars,[1] finds an accuracy as great from one set of plates; whilst Mr. F. SLOCUM, in measuring the parallax of *Nova Geminorum* (2), finds a probable error of $\pm 0''.007$ from observations spread over less than one year. It might be objected that the photo-

[1] *Groningen Publications*, No. 14.

graphic measures are differential measures, which are always more accurate than absolute measures, but it is probable that these differential photographic measures can be continued around the sky in belts and the triangulations closed with all possible accuracy. At the present time Professor H. H. TURNER is trying various methods of finding the absolute places of stars by photography at the University Observatory at Oxford. The results so far obtained are encouraging, but as might be expected with any new method, various difficulties arise and have to be combated. It is, however, quite doubtful if the probable error of a well-observed meridian star above given, 0″.05, means anything, because, after all, it depends on the position of the equinox, a very elusive point indeed.

I have laid the advantage of using galactic co-ordinates before astronomers in Circulars Nos. 2, 5 and 6 issued by the Union Observatory. In Circular No. 2, the necessary formulas are developed and tables given for the conversion of mean equatorial co-ordinates to invariable galactic co-ordinates for any year from 1750 to 1950, with a special table for the conversion of true equatorial co-ordinates to invariable galactic co-ordinates or *vice versa* for the current year 1913. The processes are illustrated by numerical examples.

The most thorough investigation of the position of the galactic plane was made by NEWCOMB and published in 1904 under the title "On the Position of the Galactic and Other Principal Planes Towards Which the Stars Tend to Crowd." Unfortunately, the principal galactic plane cannot be found very precisely because the Milky Way is a very irregular aggregation of stars, throwing out wisps and branches, whilst the zone of brightest stars is considerably inclined to it. NEWCOMB gives the following poles:—

	R. A.	Dec.
Galactic plane (omitting branch)	192°.8	+27°.2
Galactic plane (including branch)	191 .1	26 .8
Plane of Vth type stars	190 .9	26 .7

It is known that stars of the fifth type (bright-line spectra) are all close to the principal plane, but their number is small. It has further been assumed that the solar system is in the principal plane. But it is not a matter of great importance if

the assumed position of the plane is in error so long as it is nearly correct, as any small error can easily be allowed for when the progress of astronomy requires. The total change in many thousands of years will certainly be less than the change in all the present star catalogues every fifty years caused by the fictitious precession of the stars.

Besides the position of the plane, it is necessary to adopt a departure point from which longitudes are to be counted, and it is obvious that this must be a fixed point. The point actually chosen is that one which in this age will make the longitude of the apex of solar motion—the direction towards which the Sun is moving—equal to 0°. This point is chosen because a considerable portion of the proper-motions of the stars is actually due to the solar motion through space and it renders the effect of this motion in a uniform manner, in that generally all proper-motions so far as they are caused by the Sun's motion, tend toward 180° of galactic longitude. Here again a compromise has had to be made, because the apex of solar motion depends on the class of stars to which it is referred. I have adopted for 1900 the position of the apex recommended by Dr. CAMPBELL of the Lick Observatory,—namely, R. A. 18^h, Dec. + 30°—and for the plane, NEWCOMB'S determination, including the branch, so that we have—

Ascending node..	281° 6′ 0″.00	+ 4413″.57 T	— 6″.88 T^2 + 0″.186 T^3
Inclination	63 12 0 .00	+ 1967 .18 T	— 4 .56 T^2 — 0 .145 T^3
Departure point .	23 35 27 .26	+ 432 .40 T	+ 22 .46 T^2 — 0 .128 T^3

In which T indicates solar *centuries* after 1900, assuming as correct NEWCOMB'S variation of the Earth's equator and orbit.

In Circular No. 5, the advantages of using a fixed system of co-ordinates in planetary theories is insisted on, and for this fixed system, there is no reason why the galactic system should not be used. If anything, the simplifications which would thus be introduced into the planetary theories are more considerable than those already dealt with. At simplest, the motions of planets and comets are complicated, but this complication is vastly increased by adding onto their motions—both in their orbits and of their orbits—other imaginary motions, as is done at present.

In Circular No. 6, it is shown that if even a precise daily

ephemeris of a star in equatorial co-ordinates is required, which appears to be the most unfavorable case for the use of galactic co-ordinates, one can be easily and rapidly computed without any knowledge of the star's imaginary mean right ascension and declination; as an example, an ephemeris of ϵ *Orionis* is computed for the current year (1913).

Astronomers have been quite aware of the awkwardness of referring the stars and planets to rapidly shifting planes, and some attempts to get over the chief difficulties have been made. Thus, the late Dr. RISTENPART proposed that the equinox should be changed every twenty-five years, and he would call 1875, 1900, 1925, etc., normal equinoxes. He has published tables for the normal equinox of 1925. His idea would save some work, but not much; it is, in short, only a palliative. The astronomical ephemerides do something in the same direction. As an example, I will deal with the issue for 1915 of the celebrated *Connaissance des Temps,* which, as it proudly boasts, is the oldest astronomical almanac now published, as it first appeared in 1679 and has never suffered an interruption; besides this, it has always been brought up to date so punctually that it might also claim to be the youngest. For the Sun, the *Connaissance des Temps* furnishes the longitude and latitude for date and for the mean equinoxes and ecliptics of 1915 and 1920—three where one would do. Similarly for the planets, the heliocentric co-ordinates are referred to the Earth's true equinox and ecliptic of date, and to the mean equinox and ecliptic of 1920. For 732 minor planets the Gaussian Constants and their variations are given. It seems illogical to speak of constants varying; they really do not do so; nevertheless, 4,392 annual variations are specially computed for 1915. If galactic co-ordinates had been introduced, it is only three annual variations that would have been required—a saving of 4,389 out of 4,392. Lastly, for the stars, the elements of reduction are given for the mean equinox and equator of 1915 and also for 1920. And when one has got to 1920, the labor of Sisyphus will still go on, but the mountain gets a little steeper each time.

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